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SUBSTRUCTURE REPAIR USING LATEX MODIFIED SHOTCRETE

MATERIALS INFORMATION
ENGINEERING MATERIALS OFFICE

SUBSTRUCTURE REPAIR

USING

LATEX MODIFIED SHOTCRETE

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ONTARIO MINISTRY OF TRANSPORTATION AND COMMUNICATIONS

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CONCRETE SECTION

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SUBSTRUCTURE REPAIR USING LATEX MODIFIED SHOTCRETE

INTRODUCTION

Latex modified shotcrete was used on several contracts in 1983 to repair bridge substructures which had scaled due to poor air-entrainment or delaminated due to corroding reinforcing bars (caused by chloride ion penetration).

This report contains a summary of the shotcrete process and shotcrete properties, a review of the contracts which included latex modified shotcrete as a repair material, and a list of guidelines for the designer and the construction staff.

SHOTCRETE

Shotcrete is a mortar which is pneumatically applied to a surface at a great velocity.

The mortar can be applied in two ways, the dry mix method and the wet mix method. With the dry mix method the sand and cement are mixed together, then shot through the hose to the nozzle. At the nozzle the nozzleman controls the amount of water or latex (if required) added to the dry mixture. With the wet mix process all of the ingredients are mixed together then shot through the hose to the nozzle. In this case the nozzleman has no control over the water or latex quantity.

See Figure 1 for a diagram of the two methods and the advantages and disadvantages of each.

Shotcrete is an ideal repair method for substructures because it has the following properties:

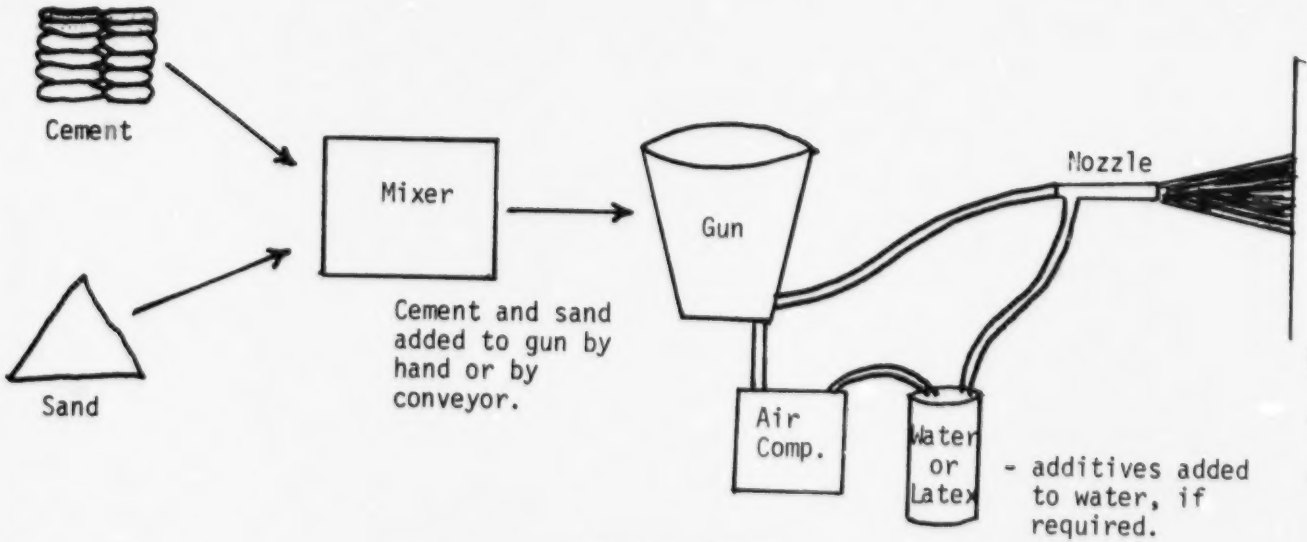
- it has zero slump and can be placed on horizontal, vertical and overhead areas.

- due to its compaction, high cement and low water content; shotcrete is relatively impermeable to water.

- it has an excellent bond with concrete and steel (as well as most other materials)

FIGURE 1

DRY MIX METHOD



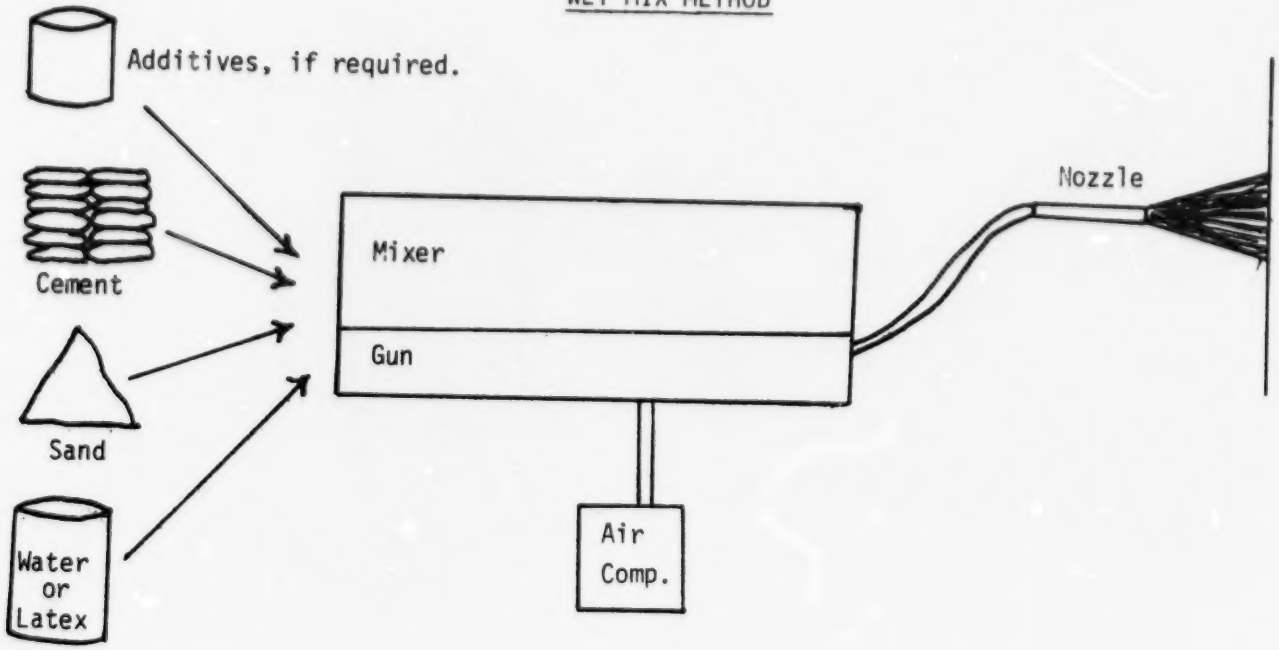
ADVANTAGES

- greater compactions
- larger hose lengths possible
- can control water and latex while spraying

DISADVANTAGES

- mix inconsistencies
- greater amount of rebound

WET MIX METHOD



ADVANTAGES

- water and latex accurately measured
- less rebound and dust
- better mix consistency

DISADVANTAGES

- lower strengths
- cannot stop production in mid batch

- it can be applied to surfaces of varying shapes and depths without the use of formwork.

When shotcrete is modified by the addition of latex the penetration of chloride ions is retarded and the durability is increased.

Although many jurisdictions allow only the dry mix method the Ministry allows either method to be used. On projects where the wet mix method has been used, the shotcrete strengths have been very good.

While shotcreting, material is lost in two ways, rebound and wastage.

Rebound is the material which does not adhere to the surface, it is composed mainly of sand. Excessive rebound is caused by too high or too low air pressures, inadequate water, and poor shooting techniques. The percentage of rebound which can be expected on vertical surfaces ranges between 15% - 30%, on overhead surfaces the range is 25% - 50%.

Wastage is the material lost during the start-up of the shotcreting and during the cleaning of the hoses. It is also material lost at any time during the shooting when the nozzleman must stop due to equipment problems.

CONTRACTS

There were nine contracts let in 1983 in which latex modified shotcrete was used to repair bridge substructures.

The mix design for the latex modified shotcrete was:

1 part cement
3-1/2 parts fine aggregate
1/3 part latex (47.5% solids by weight)

These ingredients were proportioned by dry mass on half the projects and proportioned by dry loose volumes on the other half.

The allowable water/cement ratio was 0.35. The moisture content of the sand was between 3% and 6%.

The following chart is a list of contracts which included latex modified shotcrete as a repair method.

CONTRACT	LOCATION/REGION	QUANTITY METHOD OF PAYMENT	COMMENTS
82-109	Bronte Creek Bridge - Q.E.W. Central	ft^2 (area of chipped repair areas)	- mix proportioned by mass - dry mix
82-25	Hwy.88/Hwy.400 Southwestern	m^3 (based on 385 kg/m^3, bags of cement were counted to calculate cement used)	- mix proportioned by mass - dry mix
82-87	Humber River Bridge - Hwy.27 Central	m^2 (as 82-109)	- mix proportioned by mass - wet mix
83-26	North & South Big Otter Bridge Hwy. 19 Catfish Bridge Hwy. 3 Southwestern	m^3 (as 82-25)	- mix proportioned by volume - dry mix - acrylic sealer applied to shotcrete repaired areas. - rebars were epoxy coated before shotcrete
83-308	Hwy.17/Hwy.39 Eastern	m^3 (as 82-25)	- mix proportioned by volume - dry mix - acrylic sealer applied to the entire substructure
83-43	Lundy's Lane to Tee Creek Central	ft^2 (as 82-109)	- mix proportioned by volume - wet mix - no testing required in S.P.
40-83-03 District Contract	Hoasic Bridge - 401 Eastern	m^3 (as 82-25)	- mix proportioned by volume - dry mix
83-22	Hwy.17 Ottawa Eastern	m^3 (as 82-25)	- mix proportioned by mass - shotcrete work not yet started
83-50	Hwy.401/Hwy.77 Bear Creek-Hwy. 21, Southwestern		- Vertipatch patching used to replace 1 m^3 of shotcrete

During construction, several problems and concerns became apparent due to deficiencies in the present specifications and lack of experience.

1) MIX DESIGNS WITH VOLUME PROPORTIONING

On four of the contracts the mix design was proportioned by dry, loose volumes. This caused problems with the yielding of mixes. A specific mass of sand will not always be the same volume, it depends upon the moisture content and bulking factor. Because of this the cement content of a cubic metre of shotcrete will vary with the volume of sand.

In the future, all shotcrete mix designs will be proportioned by dry mass. Since it is unrealistic to expect the contractor to have a scale on the contract at all times, the materials can be batched by volume. In order to batch by volume the factor to convert from mass to volume must be calculated (see Construction Guidelines #1 for this calculation).

2) METHODS OF PAYMENT

There were two methods of payment used on the contracts. One method was to measure the chipped area, the other to calculate the volume of shotcrete in place.

With the area method the payment was based on the area (in m^2 or ft^2) of the sections to be repaired after chipping. This method posed some administrative problems because on most of the contracts the depth of repair was greater than was shown on the drawings.

To pay for the shotcrete by the cubic metre in place, the quantity was calculated by using the factor of 385 kg of cement mixed per 1.0 m^3 of shotcrete in place. On the contracts where this method was used the bags of cement mixed were counted at the end of the day to get the quantity of cement.

The factor of 385 kg/m^3 of shotcrete in place was too low, calculations indicate that this figure should have been approximately 910 kg/m^3 (see Appendix A) for a 3.5:1 mix design. In the field the amount of cement actually used far exceeded any expectations. One contract (which was paid by the ft^2) used 22 bags of cement per cubic yard of shotcrete in place (1050 kg/m^3 of shotcrete in place). Another contract which paid for the shotcrete by the cubic metre used about 1400 kg of cement per cubic metre of shotcrete in place.

In 1984 a mix design with an aggregate/cement ratio of 4:1 will be used. The new special provision will indicate that 840 kg of cement/m^3 of shotcrete in place is to be the factor for calculating the volume quantity for payment.

In calculating this factor it is assumed that there will be an average of 50% rebound and wastage during the shotcreting operation. This means that for every 1 m^3 of shotcrete in place there must be 2 m^3 of shotcrete mixed. The 840 kg/m^3 is the quantity of cement required to mix 2 m^3 of shotcrete before placing but it creates only 1 m^3 of shotcrete in place. Because the majority of rebound is aggregates, the final mix has a lower aggregate to cement ratio than 4:1.

Three methods of payments will be outlined in the new special provision. The two methods of payment as used before and a new volume method, where the payment is calculated by measuring the volume of the areas to be repaired using the average end-area method.

3) QUALITY ASSURANCE

In order to test the strength of the shotcrete and the ability of the nozzleman, one or two test panels were shot on each contract. One panel was placed vertically, the other overhead, all the panels had wire mesh in them, a few had reinforcing bars.

In all of the special provisions the strength tests were to be done by testing 75 mm (3") cubes cut from test panels. Since it is difficult to cut 75 mm (3") cubes in the field, 50 mm - 100 mm cores were taken instead.

The cores were also checked for rebound, air, and sand pockets behind the mesh and the bars, and in the corners. On all of the contracts some pockets of rebound, sand, and air were found behind at least one core, generally the ones taken near the edges of the panel.

The new special provision requires that the contractor shoot 2 test panels, one in the overhead position and one in the vertical position. Wire mesh and reinforcing bars will be required in each of the panels. The bars are to be placed every 250 mm in only one direction. (If there is no overhead shotcrete work on the contract, only the vertical panel needs to be shot.)

From each of the test panels 12 cores must be taken. Six of the cores will be taken between the reinforcing bars to be tested for compressive strength; two to be tested for a seven day strength of 20 MPa and four to be tested for a 28 day strength of 30 MPa. The other 6 cores will be taken over the reinforcing bars to check for rebound, sand and air pockets.

The latex modified shotcrete test panels and coring are to be paid for under a separate lump sum item in the future.

4) EDGES OF THE REPAIR AREAS

Some of the contracts required that a 25 mm sawcut be made around the edges of the area to be repaired. This was the slowest portion of the work.

The new specification will call for chipping in a neat line, to a depth of 25 mm along the edges of the area to be repaired. The 25 mm depth is required because the latex-modified shotcrete cannot be feather-edged.

5) FINISHING

For aesthetic reasons finishing of the latex modified shotcrete was required on some contracts. But the latex modified shotcrete cannot be finished like regular concrete because of the latex modifier. Trowel finishing will cause the latex modified shotcrete to crack and tear.

Shotcrete modified with latex can only be finished by slicing with a sharp steel trowel and this should only be done around the edges.

6) CURING

The special provision on all contracts called for a 3 hour delay between completing the shotcreting and applying the water spray or fog mist curing for 24 hours. This 3 hour delay was to allow the latex film to develop. But the delay also caused surface cracking in the shotcrete, especially areas which were exposed to the sun.

The new specification will call for a 24 hour fog mist, or wet burlap curing as soon as it is possible without causing damage to the shotcrete surface but before 1.5 hours. After the 24 hour damp curing the surface will air dry for 72 hours allowing the latex film to form.

GUIDELINES FOR DESIGN

1) When choosing one of the methods of payment from the new special provision the following should be considered:

METHOD A (volume of shotcrete based on the volume of the area to be repaired)

This method is best suited to contracts where the areas to be repaired vary in depth and are easy to measure.

METHOD B (volume of shotcrete in place based on the quantity of cement used).

This method is best suited in situations where the areas to be repaired vary in depth and are difficult to measure.

METHOD C (area of sections to be repaired - m^2)

This method is best suited to contracts where the areas to be repaired are a constant depth.

2) The benefits and consequences of using an acrylic sealer on concrete are not known. The shotcrete does not need to be sealed as it is almost completely impermeable to chloride ions and water due to the latex modifier and general properties of shotcrete. If a designer chooses to use an acrylic sealer it should be applied to those areas not repaired with latex modified shotcrete.

3) The properties of latex modified shotcrete make it unnecessary to epoxy coat the reinforcing bars. The force of the sand hitting the reinforcing bars could cause scratching of the epoxy. Epoxy coating the bars could also increase corrosion of adjacent non-coated bars. Cathodic protection, which may become a future rehabilitation method, cannot be used in areas where the bars have been epoxy coated.

4) The substructure should not be repaired until the deck, including expansion joints, have been repaired. Many of the problems on substructures are caused by saltwater leaking from joints, cracks and poorly placed drains in the deck. If these are not repaired the problems of substructure deterioration will continue.

5) The bond between the shotcrete and existing concrete is very strong (if the shotcrete is applied correctly) and there is no need to apply a coat of the latex modified slurry or a slush bond coat before shotcreting.

6) When the average depth of a repair area is greater than 150 mm and larger in area than 1 m x 1 m placing regular concrete (with the required work form) should be considered.

7) If there is less than 1 m^3 of repair work to be done in total, a patching material should be considered. A list of suitable patching materials will be issued in the fall of 1984.

8) If the latex modified shotcrete is to become a load bearing part of the structure, a mix design of 1 part cement, 3-1/2 parts fine aggregate, 1/3 part latex (by mass) should be used.

9) Latex modified shotcrete cannot be finished to match the existing structure.

10) The following tender items must be included when shotcreting is used on a contract.

1) Latex Modified Shotcrete
2) Latex Modified Shotcrete Test Panels (including coring)
3) Removal of Concrete
4) Sandblasting Concrete Surfaces and Reinforcing Steel
5) Access to Work Area (Work Platform Scaffolding)

GUIDELINES FOR CONSTRUCTION

1) The area to be repaired must be carefully checked before the shotcrete is applied, to ensure that all delaminated, scaled and loose concrete is removed, the reinforcing bars are cleaned of all corrosion, bars are tied together and the wire mesh is secure.

2) The mix design will be proportioned by mass in the special provisions but it can be volume batched on site, if scales are not available.

In order to batch by volume the density of the dry loose sand and the moisture content of the sand must be measured. The densities of water, latex and cement are known.

The following sequence should be followed in order to get a mass to volume conversion factor for the sand

a) Measure the moisture content of the sand (A).

b) Weigh an empty air void meter (B). The volume of an air metre is 1/4 ft^3 or 0.00708 m^3.

c) Fill the meter with loosely packed sand at the above moisture content and weigh (C).

d) Mass of sand in the air metre is D.

$D = C - B$.

e) Dry mass of sand is E.

$$E = D - \frac{D\,(A)}{100}$$

f) Mass to volume conversion factor is:

$0.00708 m^3 \div E$

Example

The mass of sand required per 40 kg bag of cement is 4 x 40 kg = 160 kg.

The moisture content of the sand on the site is 4% (A).

The mass of the air metre is 4.4 kg (B), the volume is 0.00708 m^3.

The mass of the air metre filled with loosely packed sand at 4% moisture content is 17.4 kg (C).

The mass of the loosely packed sand at 4% moisture is:

$$C - B = D$$

$$17.4 - 4.4 \text{ kg} = 13.0 \text{ kg}$$

The dry mass of sand is:

$$D - D(A)/100 = E$$

$$13.0 - 13.0(4)/100 = 12.48 \text{ kg}$$

The mass to volume conversion factor is:

$$0.00708 \text{ m}^3/E = 0.00708 \text{ m}^3/12.48 \text{ kg}$$

$$= .000567 \text{ m}^3/\text{kg}$$

The volume of loosely packed sand at 4% moisture content required for a 40 kg bag of cement is:

$$160 \text{ kg} \times .000567 \text{ m}^3/\text{kg} = .090 \text{ m}^3$$

This conversion will apply only when the sand is at the moisture content measured.

When batching this way the moisture content must be checked each day and it must be kept constant or a new conversion factor calculated for moisture contents that differ by more than 0.5%.

3) The mixing process must be carefully observed at all possible times to assure that the mix is being properly measured.

4) While shooting the test panels and the surfaces to be repaired the inspector must ensure that the following is done:

- The nozzelman directs the shotcrete at right angles to the surface, shooting at a slight angle only to get behind the reinforcing bars.

- The nozzle should be between 0.6 m and 1.0 m from the surface being shotcreted.

- Rebound and wastage are kept to a minimum.

- The shotcrete has a consistent mix, that there is no surging or pulsing of the sand, cement, water or air pressure. This will cause an uneven mix on the surface ranging from sandy areas to areas where the shotcrete appears runny.

- When using the dry mix, the dry sand and cement are thoroughly mixed before shooting.

- When using the wet mixed, all ingredients are thoroughly mixed before shooting.

5) The contractor should set up the test panels so that he can apply the shotcrete in a proper manner. The panels should be braced so they do not vibrate.

6) After each layer of shotcrete is applied, the inspector must check for sandy areas and rebound and air pockets. All of these must be removed before the next layer of shotcrete is applied. The surface must also be brushed of loose sand before applying the next layer.

7) After the final set the inspector must sound the repair(s) for drummy areas. This is done by hammer tapping for hollow or dull sounding areas which indicate that there are air or rebound pockets in the shotcrete that must be chipped out and replaced.

8) The hoses used during the shotcreting process should be as short as possible.

All equipment should be thoroughly cleaned after each day of operation. Hoses must be emptied after each batch.

9) If possible cores should be taken from the finished shotcrete to check for rebound, sand and air pockets.

10) The water cement ratio must be kept below 0.35. Dilution of the latex modifier with water must not be permitted.

APPENDIX 'A'

4:1 Mix

X = mass of cement in 1 m^3 of shotcrete before placing

	MASS (kg)	RELATIVE DENSITY	ABSOLUTE VOLUME (m^3)
CEMENT	X	3.15	X/3150
AGGREGATE	4X	2.70	4X/2700
LATEX*	.33X (.475)	1.06	.33X(.475)/1060
WATER**	.35X	1.00	.35X/1000
AIR (4%)			.04

$$.00031746X + .0014814X + .00014788X + .00035X + .04 = 1\ m^3$$

$$.002297X = .96\ m^3$$

$$X = 418\ kg.$$

assuming 50% of the material will be lost in rebound and wastage then the required amount of cement to get 1 m^3 of in-place shotcrete is:

418 kg x 2 = 836 kg/m^3 insitu

(840 kg/m^3 used in the new S.P.).

3.5:1 Mix

Y = mass of cement in 1 m^3 of shotcrete before placing

	MASS (kg)	RELATIVE DENSITY	ABSOLUTE VOLUME (m^3)
CEMENT	Y	3.15	Y/3150
AGGREGATE	3.5Y	2.70	3.5Y/2700
LATEX*	.33Y (.475)	1.06	.33(.475)Y/1060
WATER**	.35Y	1.00	.35Y/1000
AIR (4%)			.04

$$.00031746Y + .0012963Y + .00014788Y + .00035Y + .04 = 1\ m^3$$

$$.00211164Y + .04 = 1$$

$$Y = 455\ kg.$$

assuming 50% of the material will be lost in rebound and wastage then the required amount of cement to get 1 m^3 of in-place shotcrete is:

455 kg x 2 = 910 kg/m^3 insitu

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* latex solids only

** this is the TOTAL water content, including the moisture in the aggregate and the water in the latex.